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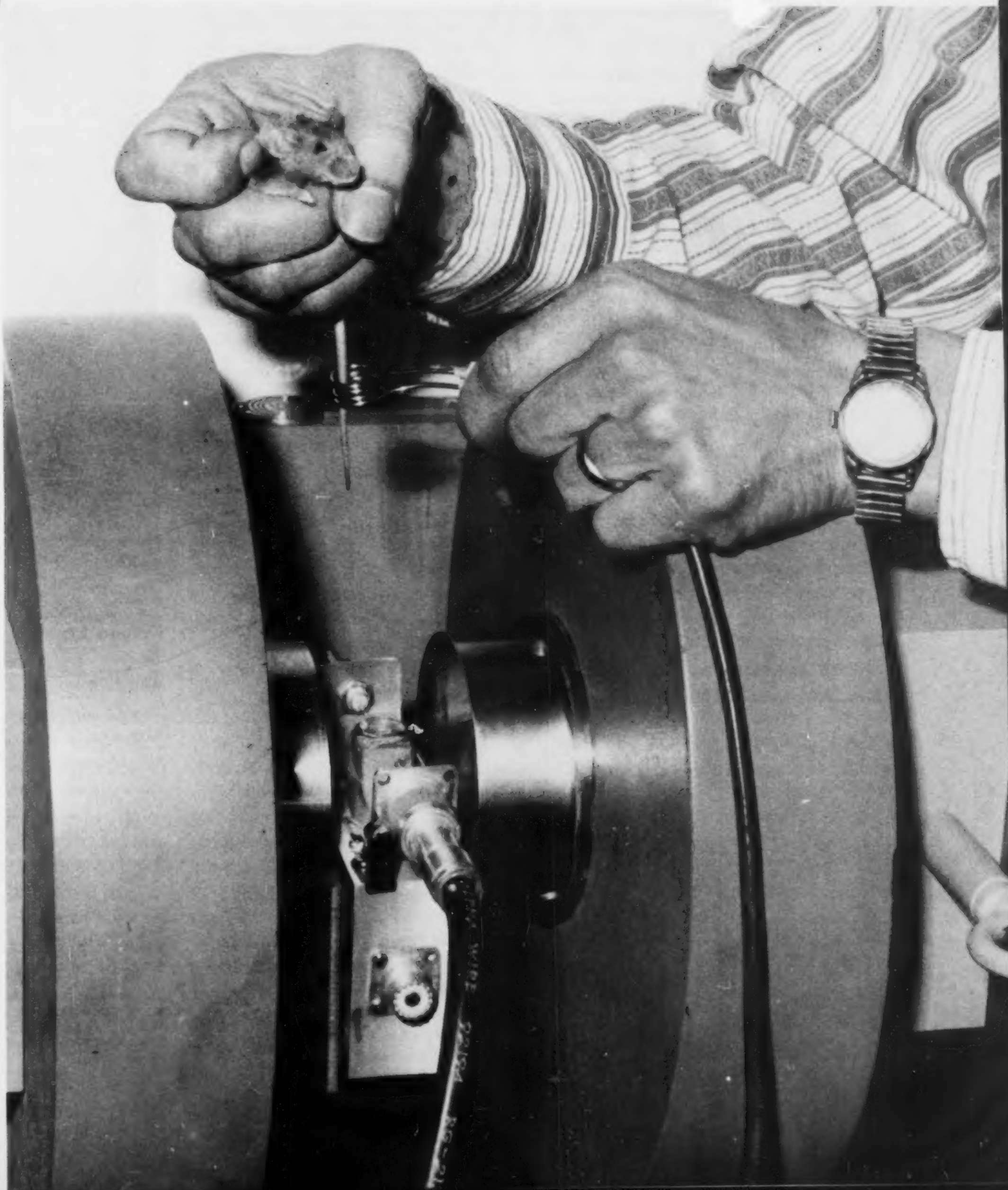
NATIONAL BUREAU OF STANDARDS

Technical News Bulletin



UNITED STATES DEPARTMENT OF COMMERCE

National Bureau of Standards

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Technical News Bulletin

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Cover: Cancer has been detected in the tails of living mice with a nuclear magnetic resonance technique. See page 27.

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The National Bureau of Standards serves as a focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. For this purpose, the Bureau is organized as follows

The Institute for Basic Standards

The Institute for Materials Research

The Institute for Applied Technology

The Institute for Computer Sciences and Technology

Center for Radiation Research

Center for Building Technology

The TECHNICAL NEWS BULLETIN is published to keep science and industry informed regarding the technical programs, accomplishments, and activities of NBS.

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CANCER DETECTED IN LIVING ANIMALS USING NUCLEAR MAGNETIC RESONANCE

Cancer has been detected in living animals for the first time by a technique called nuclear magnetic resonance (NMR).

Scientists at the Bureau have successfully detected differences between normal tissue and malignant tumor growth in living mice. NMR requires neither anesthesia nor surgery and provides almost immediate results. Although the first experiments using NMR for cancer detection in living animals were done on mice,[1] the scientists feel that further development of the technique may possibly provide a safe, painless tool for the detection and monitoring of tumor growth in humans.

The studies were performed by NBS materials scientists Drs. Irwin D. Weisman and Lawrence H. Bennett in cooperation with Dr. Louis R. Maxwell, Sr., a physicist retired from the U.S. Naval Ordnance Laboratory, and Drs. Mark W. Woods and Dean Burk of the National Cancer Institute.

NMR was first discovered in 1945 by E. M. Purcell and F. Bloch who later shared the Nobel Prize for this work. NMR has now become a well established technique with applications in analytical chemistry and solid state physics. Materials are studied by utilizing the interaction of the magnetic moment of the nucleus with magnetic fields in the material. Nuclear magnetic moments behave like weak bar magnets. When the atoms are placed in a uniform, external magnetic field, the nuclear magnetic moments align themselves parallel to the external field. The moments can be rotated away from the field direction by applying radio-frequency (rf) energy at the resonance frequency. When the rf energy source is removed, the nuclei return to their positions parallel to the magnetic field in a characteristic, measurable time, known as the spin-lattice relaxation time (T_1). The duration of T_1 is influenced by the surroundings of the atom and the motion of other atoms. Changes in T_1 reflect changes in the atomic surroundings.

In the NBS studies, measurements on protons in tissue water of the tail were made using a conventional pulsed NMR spectrometer. The mouse's tail was placed in a wire coil, which formed the spectrometer probe. The probe was situated between the pole faces of a laboratory dc electromagnet.

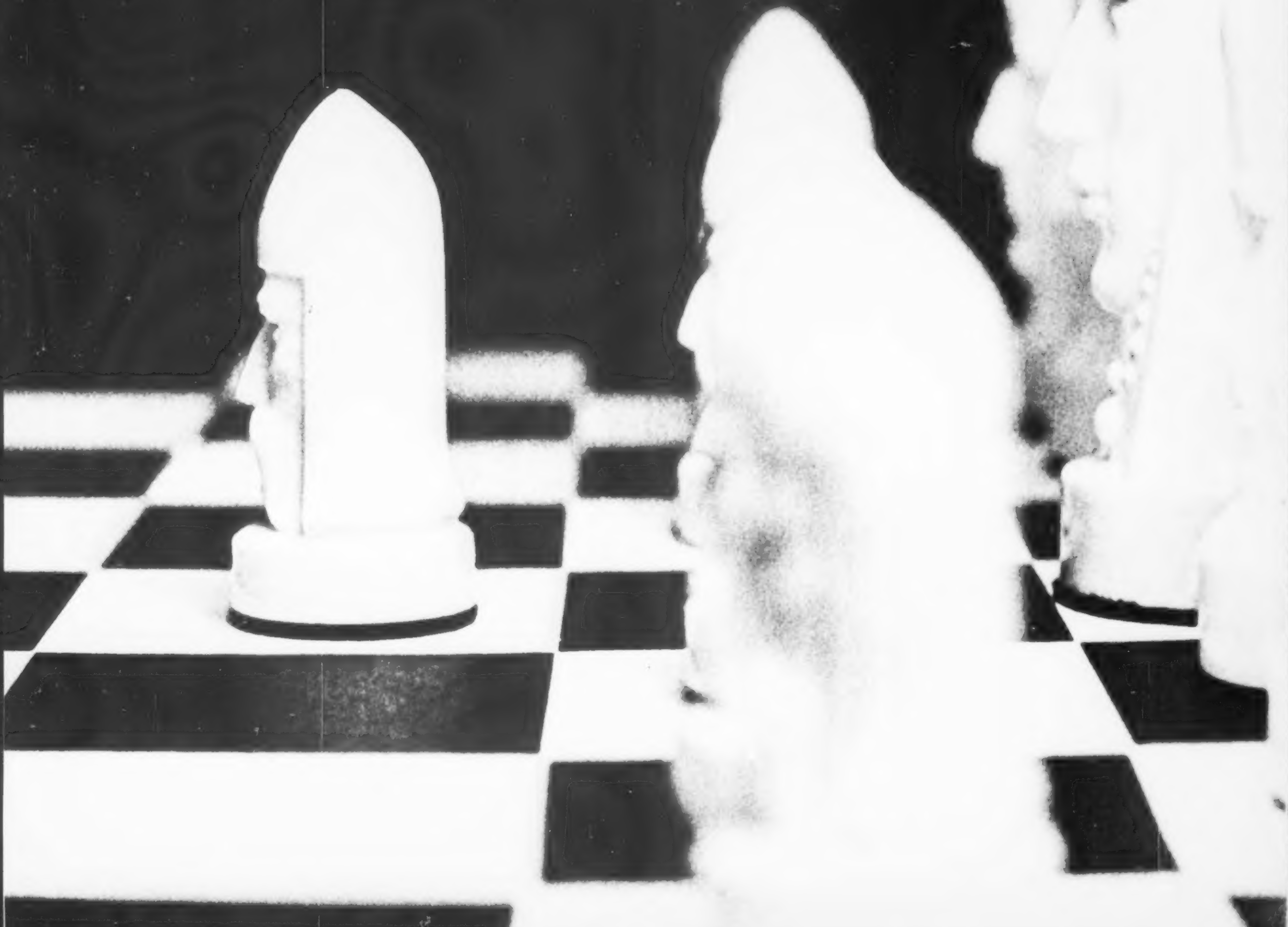
Measurements taken over a period of time revealed the growth of the tumor, a transplanted malignant melanoma. A change from normal to malignant tissue was evident in the relative change of NMR signals associated with the tumor and normal tissue relaxation times. The tumors displayed proton nuclear spin-lattice relaxation times of about 0.7 second contrasted with the simultaneously measured normal tail tissue proton relaxation times of about 0.3 second. The analysis was performed on DBA mice.

Using magnets with larger sample space, experiments could be performed on other animals and even humans. Coils of different designs might be adapted to fit various parts of the body. If this technique can be developed and applied at a practical level, competent technicians should be able to test a patient in a matter of minutes. Perhaps NMR could take its place beside thermography and radiography as a nonsurgical technique for cancer detection and the analysis of cancer growth rates.

[1] Weisman, I. D., Bennett, L. H., Maxwell, L. R., Sr., Woods, M. W., Burk, D., Recognition of cancer *in vivo* by nuclear magnetic resonance, Science **178** (Dec. 22, 1972).

City Games People Play

The Bureau is offering to state governors, city mayors and managers, Federal agencies, and public officials a practical method that permits them to directly involve themselves in "playing games" with a typical city. Aided by a computer, the game players see precisely the ramifications their decisions have on a city during game play. Called "CITY GAMES," this simulation of a city's day-to-day operations compresses into a few days of game playing a representation of what could happen to a city in 5 to 10 years.



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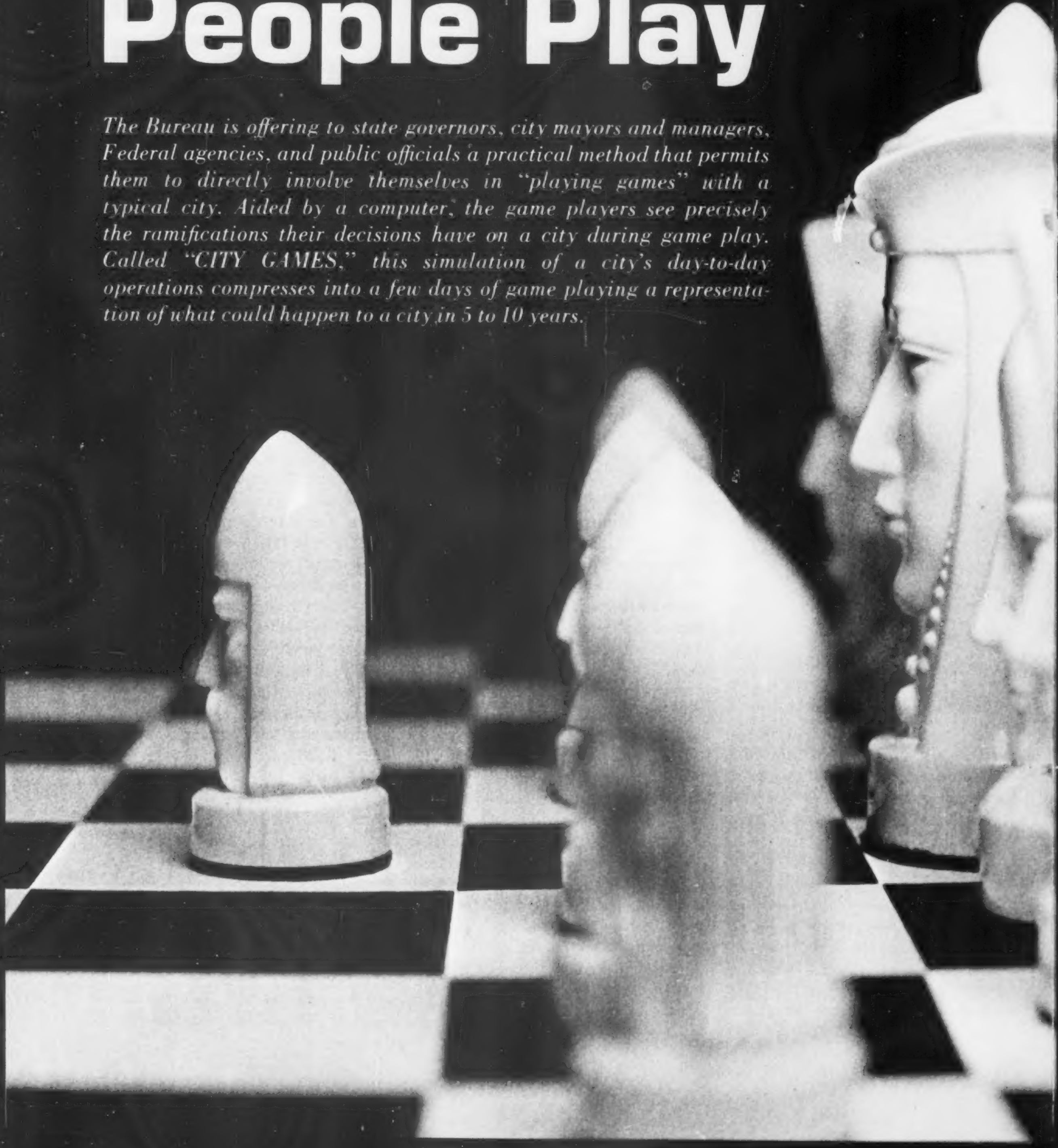

To begin to cope with their problems, most city decision makers—from the mayor and city manager on down—must accept and put into practice a new concept. And that concept is the postulate (proven pragmatically) that every city operates as a "closed system." In the context of a city, a closed system simply means that all parts of the city—its multiplicity of operating and planning units, the mayor's office, and the citizens themselves—function in a closely interrelated and interdependent way. A change in one part of the closed system affects either directly or indirectly the rest of the system.

This idea has been known intuitively for years. What transforms the idea into a practical problem-solving concept is the computer and the city model the computer manipulates.

BACKGROUND OF CITY GAMES

Originally conceived by Dr. Peter House and Mr. Philip Patterson (both now with the Environmental Protection Agency) as a laboratory for political scientists to test their theories, CITY GAMES was acquired by the NBS Technical Analysis Division after its great potential for training in city problem solving was recognized. Dr. House and his associates at a former company he headed, developed the models to the point where they now are the most highly sophisticated city models in existence. The model can even account for a city's *Social Sector*—its citizen power-measured qualitatively as the "level of dissatisfaction." (Level of dissatisfaction comes prominently into play around election time, since elections are the events during which satisfaction/dissatisfaction is translated into support or change of government. CITY GAMES, however, also takes into account strikes, boycotts, and other forms of social action.)

PREPARING FOR CITY GAMES

Because CITY GAMES is built around three major elements or sectors—*Economic*, *Social*, and *Government*—players are divided into these three sectors and are charged with the responsibility for their efficient management. Each sector has a participating leader elected by the players. The city model selected for game playing may be a "typical" city, or it may be the players' own city. Before game time, certain information may be discarded to simplify the game or it may remain as is. Thus the city is *defined* and acts as the data file upon which the computer-stored city model will work. This defined city is called the "starting city" and the files which define it must not be confused with the stored city model itself. The starting city files can be altered by the user and changes in these files may affect the output of the computer; they will *not*, however, affect *how* the output is computed. The stored city model, on the other hand, is *not* readily *user-alterable;* it defines fixed relationships between various data in the city file and it alone determines *how* the output is computed.

GAME PLAYING BEGINS

After a city had been defined by data such as population and voter distribution, zoning information, employment statistics, and so forth, the game begins. First each player receives various computer printouts. These may include a map of the city divided into square miles with each square displaying such data as land ownership, zoning, type of roadways, kind of utilities, and so forth. Each department head receives a printout of information with which he is vitally concerned; for example, the social sector leader receives data on population migration, environmental conditions, and the moods of the populace in various city areas (dissatisfaction levels). There can be as many as 60 different types of printouts, depending on the complexity of the city model.

Each player studies his computer printout to evaluate his status as an individual and as a team member. Each team defines its specific problems, establishes objectives, and develops strategies. Then various groups gather for informal sessions. As with a real city, each group realizes that it will not get its every wish satisfied and so bargaining begins, trade-offs are made, deals consummated. Eventually each group arrives at final decisions for actions to be taken in that particular round of the game. These decisions are then entered into the computer via a special code and the model is run. The computer then prints out a new series of data representing the changed city.

Players see immediately the far-reaching effects of their decisions. For example, a situation like the following (based on sample data from one city) may occur. Developers of land for industrial use observed an unexpected phenomenon: The city's bus system had suddenly become overloaded to the point of complete breakdown. Why? Because city planners did not forsee that there was no pool of workers living near the newly industrialized suburban area and made no plans to transport workers to their new jobs. The computer printout also revealed, not surprisingly, that "dissatisfaction" levels rose sharply among voters in residential areas near the new suburban industrial plants. Plummeting property values in that area accounted for this. Clearly, the city's mayor was affected by the closed chain of events. Voter militancy rose, particularly among blue collar workers, because the city administration had failed to keep old industry and attract new plants to the city's own urban industrial park. With elections coming up

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NBS MEASURMENTS SHOW SIGNIFICANT

TEMPERATURE SCALE DIFFERENCES

Accurate gas thermometry measurements made at the Bureau show a nearly linear difference between the thermodynamic temperature scale and the International Practical Temperature Scale of 1968 (IPTS-1968) over the range 0-140 °C. This difference amounts to 0.03 °C at 100 °C and is nearly 7 times larger than the estimated uncertainty stated in the IPTS text. Knowledge of this variance could lead to revisions of existing thermodynamic tables, to more accurate calculations of thermodynamic quantities in the future, and perhaps, when more data are available, to changes in the IPTS.

The NBS measurements are the result of a long-term project in gas thermometry. Dr. Leslie Guildner of the Heat Division heads the effort, working with Mr. Robert Edsinger and Dr. Richard Anderson.* Dr. Harold Stimson, who retired from NBS in 1960, guided early work in this area.

The Kelvin thermodynamic scale of temperature, part of the International System of Units, has its zero at absolute zero, and is defined by assigning a value to one fixed point, the triple point of water (273.16 K or 0.01 °C). Values of temperature can be determined on the thermodynamic scale by measuring any phenomenon which can be expressed simply enough in terms of the laws of thermodynamics, and which can be realized experimentally at 273.16 K with sufficient accuracy. However, at most temperatures, "thermodynamic" thermometers have always been impractical for routine measurements. This situation led to adoption of an international scale in 1927 by the 7th General Conference on Weights and Measures. Various measuring instruments are utilized for realizing the IPTS—the platinum resistance thermometer from 13.81 K to 630.74 °C, the thermocouple from 630.74 to 1064.43 °C, and the optical pyrometer above 1064.43 °C. While the IPTS was formulated to agree as closely as possible with the thermodynamic scale, accurate measurements such as those made by the NBS group show that the actual differences existing between the two scales are still sizable. Typically, values of temperature on the thermodynamic scale are determined by applying corrections to the values measured on the IPTS, and as knowledge of the relation between the two scales improves, the corrections can be modified.

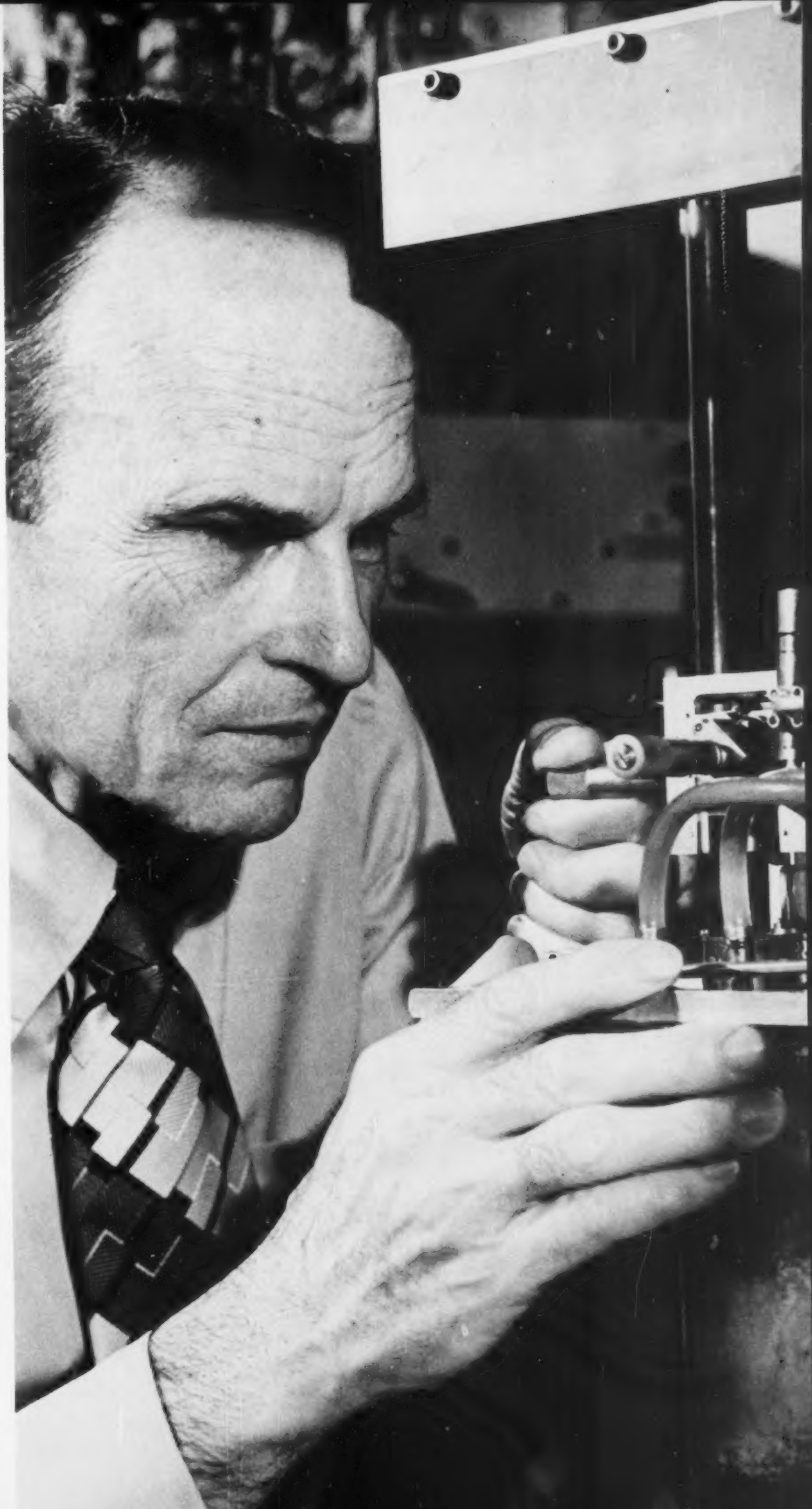
The thermodynamic relationship used for a gas thermometer is the ideal gas law, $PV = nRT$, where P = pressure, V = volume, n = moles of gas, R is a constant and T = thermodynamic temperature.

In theory at least, a container of gas makes a convenient "thermodynamic thermometer." All that has to be done is to measure the pressure of the gas at the temperature of the triple point of water and, after heating the container, measure the new pressure. If the container holds all the gas, and does not change size, and if the gas is ideal, one need only to determine the ratio of the pressures to find the ratio of the values of the temperatures. (This ratio technique eliminates the need to know the volume of the container and the number of moles of gas.) It sounds simple, but in reality this technique requires measurement sophistication of the highest order.

The NBS work put a special emphasis on the problems of sorption. Helium, a nonadsorbed gas, was introduced into a 450 cm^3 cylinder of Pt-20 percent Rh. The helium had been cleaned to remove adsorpable impurities by a special purification train and, before filling, the cylinder had been baked for 30 days at 650 °C while being evacuated by an ion pump. The thermal expansion of the Pt-20 percent Rh was measured interferometrically so that the change of the cylinder's volume with temperature could be compensated for. A stirred oil bath was used to maintain the cylinder at the various temperatures, and could be controlled within a few ten thousandths of a degree Celsius.[1] In all cases the starting temperature was that corresponding to the triple point of water. The temperature was measured by platinum resistance thermometers, which were used to determine the corresponding IPTS temperatures throughout the range. Measurements were made at various starting pressures

*Now at the Physikalisch Technische Bundesanstalt (West German standards laboratory) working on low-temperature gas thermometry.

Dr. Guildner makes a pressure adjustment during a measurement with the gas thermometer.



ranging from 0.2 to 1 atmosphere so that results could be extrapolated to zero pressure.

While all elements of the measurement system were conceived and constructed with extreme care, the measurement accuracy of the gas thermometer depends most of all on the world's most precise manometer.[2] Pressure ratios measured with this device are accurate to within 1.5 parts in 10^6. In brief, this manometer consists of three connected cells of mercury; the center cell can be supported above the other two on a column of gage blocks. Since the height of the upper cell above the lower cells is accurately defined by the gage blocks, the pressure of gas in the lower cells required to support the column of mercury in the upper cell lines can be calculated quite accurately. Again, the realization of this concept was not easy. Capacitance techniques are used to establish the level of mercury in each cell; the mercury must be very pure; special articulated joints were fabricated to permit easy, leak-free motion of various components; and the temperature must be known to ± 0.006 °C to reduce the uncertainty of the density of mercury to one part per million. The manometer is housed in a special room two stories below the laboratory floor, with a foundation resting on earth and independent of building footings.

The gas within the gas thermometer is isolated from that within the

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NBS MEASURES NOISE IN TRUCK CABS

■ Large trucks can be quite noisy, not only to people outside the truck but to the driver in the cab as well. This continual noise can contribute to driver fatigue, may degrade the ability of the driver to safely perform his duties, and, if loud enough long enough, can lead to a partial loss of the driver's hearing.

To fill the need for valid data on noise levels inside trucks, the Bureau has made an extensive series of measurements on typical modern trucks.[1] These measurements, made under the sponsorship of the Department of Transportation (DOT) and with the full cooperation of the American Trucking Associations, may lead to development by DOT of a simple, single interior noise measurement that correlates well with over-the-road measurements, and which may be used in tests to insure adequate driver protection.[2]

The research program was directed by William Leasure; an NBS team made the noise measurements at the Wallops Island, Va., research runway operated by NASA. Fifteen trucks—14 tractor-

trailers and one delivery van—were used as test vehicles. Of the 15, 13 had diesel engines, two had gasoline, with mileages running from under 2,000 to over 360,000.

Interior measurements were taken with a microphone located 6 inches from each ear of the driver, with data recorded on a tape recorder carried in the cab. While the primary interest was in interior noise levels, exterior levels were also measured simultaneously with a series of five microphones placed on a line 50 feet from the center line of the truck lane and a sixth microphone located at 25 feet. These data are needed in order to evaluate the effect of total truck noise on the community.

Interior and exterior measurements were made on each truck during a series of stationary and moving tests. Interior measurements were made with windows open and closed. The stationary measurements were made while the engine was idled, accelerated at wide-open throttle to governed rpm, and at stabilized high idle, while the moving tests consisted of acceleration at full throttle (to a maximum speed of 35 mph) and deceleration at closed throttle. The moving tests follow the procedure outlined in SAE Recommended Practice J 366a, Exterior Sound Level for Heavy Trucks and Buses. All data tapes were analyzed at NBS, a graphic display of A-weighted sound level versus time being produced for each microphone, each run.

The data show that in many cases the noise level in the cab exceeded 90 dB(A). For example, during acceleration of truck number 4 in the series the noise level with windows open was 96 dB(A) at the left ear, 94 at the right, the same numbers being obtained with the windows closed. (Table 1 summarizes the maximum interior measurements on this vehicle.)

The 90 dB(A) value is an important one since it is the limit set under the authority of the Occupational Safety and Health Act for noise exposure during an 8-hour work day. The intent of these regulations is to reduce the risk of permanent noise-induced hearing damage. Higher noise levels—up to 115 dB(A)—require shorter exposures. For every 5 dB increase there is a halving of allowable exposure time, e.g., 4 hours allowable at 95 dB(A). The Department of Transportation is proposing that these criteria be applied to protection of truck drivers, and what they are trying to do is make a single interior stationary measurement that correlates well with over-the-road measurements. The NBS data provide solid basis for such a procedure and a preliminary DOT proposal is to make a right ear, window closed measurement while the engine is run at fast idle. However, more over-the-road data (which DOT is presently acquiring and evaluating) are needed before a firm correlation can be established.

[1] Leasure, W. A., Jr., Quindry, T. L., Mathews, D. E., and Heinen, J. M., Interior/Exterior Noise Levels of Over-the-Road Trucks: Report of Tests, Nat. Bur. Stand. (U.S.), Tech. Note 737, 314 pages (Sept. 1972).

[2] Close, W. H., and Clarke, R. M., Truck Noise—II, Interior and Exterior A-Weighted Sound Levels of Typical Highway Trucks, Department of Transportation Report OST/TST-72-2, 90 pages (July 1972).

TEST	RUN	WINDOWS	SOUND LEVEL, dB(A) MICROPHONES LEFT EAR	RIGHT EAR
1. Low Idle (Stationary)	1	Open	75	77
	2	Closed	78	77
2. Acceleration (Stationary)	3	Open	—	—
	4	Open	93	94
	5	Closed	—	—
	6	Closed	93	91
2. High Idle (Stationary)	3	Open	93	92
	4	Open	93	94
	5	Closed	92	90
	6	Closed	92	92
3. City Start Up	7	Open	95	95
	8	Open	95	95
	9	Closed	95	95
	10	Closed	95	95
4. Acceleration	11	Open	96	95
	12	Open	96	94
	13	Closed	96	94
	14	Closed	96	94
5. Deceleration	15	Open	94	94
	16	Open	93	94
	17	Closed	96	94
	18	Closed	95	93

James Heinen makes a sound level recording within a truck cab while Wally Drummond revs up the engine.

OPTICAL RADIATION NEWS

Optical Radiation News (ORN) is intended to serve as a means of communication among workers in industry, universities, and government agencies involved in radiometry and photometry. ORN will focus on developments in the laboratory, in the published literature and at the council table, which are of interest to its readers.

IMPROVED SCALE OF SPECTRAL IRRADIANCE

An improved scale of spectral irradiance has been realized in the wavelength range from 250 to 800 nm. The new scale is expected to be extended to 2,000 nm by February 1973, and to 2,500 nm by July 1973. The estimated total uncertainties vary from 3 percent at 250 nm to 1 percent at 800 nm, and the differences between calibrations performed on the new and old scales vary from 12 percent at 250 nm to 0.3 percent at 450 nm and 4 percent at 800 nm. (Values determined on the new scale are lower than those on the old.)

Spectral irradiance is the most extensively used radiometric quantity in the National Measurement System, and a large number of requests have been made for calibrations on the new scale. In the next 6 months, the new scale will also be used at NBS in an international comparison with other National laboratories, in realizing a more accurate color temperature scale, and in determining the maximum spectral luminous efficacy (Km) associated with the NBS scale of luminous intensity.

The method developed for realizing the improved scale is based on adjusting the spectral radiant flux, passing through a small area, from a calibrated radiance source until it is equal to that passing through the same area, from an irradiance source. The spectral irradiance E_λ can then be obtained from a measurement of the projected solid angle of the radiance source and the known spectral radiance L_λ. An integrating sphere is placed between the small target area and the spectro-radiometer used to determine the equality of the two fluxes. This is done to avoid errors due to the differences in polarization, uniformity of field, and solid angle occurring between the flat filament radiance source, which is imaged at the area, and the coiled filament irradiance source, which is used without imaging.

Figure 1 is a schematic diagram of the experimental apparatus set up at NBS for applying the method described above. The integrating sphere may be rotated about the axis indicated in the figure so that either the image of the strip lamp or the desired field point for the irradiance is accurately positioned on the 0.6×5.6 mm entrance port of the sphere. The strip-lamp current is adjusted so that at each wavelength setting of the monochromator the detector output is the same for either L_λ or E_λ. Thus detector and electronic nonlinearity are unimportant. As the spectral radiance of the image is determined by directly comparing it to a spectral radiance standard, the reflectance of the mirror, M, need not be determined. The projected solid angle can be computed from the easily measured distances associated with it.

Various things have been done to provide a signal to noise ratio sufficiently large to not seriously limit the irradiance determination. Since the transmittance of the sphere is inversely proportional to the inner surface area, a 1-inch sphere is being used. A multiplier phototube with a high quantum efficiency and low dark current has been selected to be used from 250 nm to 800 nm. A small (0.4×2.5 mm) cooled PbS cell, with a specially designed optical system for demagnifying the exit slit of the monochromator, will be used from 650 to 2,500 nm. A low-level direct current amplifier is used with the phototube and a very stable lock-in type amplifier and chopper system with the PbS cell. An electronic integrating system accurate to better than 0.1 percent for integrations up to 15 minutes has been developed.

NEW NBS TECHNICAL NOTE

NBS Technical Note 594-4, The Impact of Radiometry and Photometry and the Role of NBS, is now available.[1] This publication, the fourth in a series on Optical Radiation Measurements, was authored by Bruce Steiner.

This note begins by describing recent technical growth in electro-optics that has led to serious discrepancies among measurements. New types of technology, broadened spectral range and distribution, extremely high and low flux levels, pulsed measurements, and new public interest in optical radiation are surveyed. The assignment of measurement responsibility and the impact of optical radiation measurements on various technological is-

sues, several public issues, the energy crisis, meteorology, pollution monitoring, remote sensing of the earth, crime prevention, and agriculture are reviewed. Alternate approaches to the measurement problems are explored. Finally the role of NBS is surveyed: the various functions required, the reasons for NBS involvement in optical radiation measurement, and the present NBS program.

This report represents the findings of a major issue study conducted to assess U.S. radiometric and photometric measurement needs for the Department of Commerce. It is being published as a Technical Note in response to the wide public interest shown in this subject.

THIRD CORM MEETING

The third meeting of the Council for Optical Radiation Measurements (CORM) took place in San Francisco on October 16-17, 1972, under the chairmanship of Edward S. Steeb of General Electric. The main topics of the meeting were the NBS response to the recommendations of the Council report, "Pressing Problems and Projected National Needs in Optical Radiation Measurements—A Consensus of Services Desired of NBS," and a proposed CORM organizational structure to facilitate the future efforts of the Council

Dr. Henry J. Kostkowski, Chief of the NBS Optical Radiation Section, noted that the existing Bureau program matched reasonably well with the CORM requests within the framework of the present NBS budget, but would not meet some of the needs as soon as desired. He felt that with a more detailed understanding of the needs, through more specific discussions on problems with CORM members, details of the program could be altered to yield a quicker response to needs.

NBS programs and accomplishments were outlined in incoherent radiometry and photometry by Dr. Kostkowski and Don McSparron, in laser power and energy measurements by Dr. Dale West, and in densitometry by Dr. Chris Kuyatt. Dr. Georg Bauer, Chief of the Optics Division of PTB, Braunschweig, Germany, described the work in optical radiation measurements at that national standards laboratory.

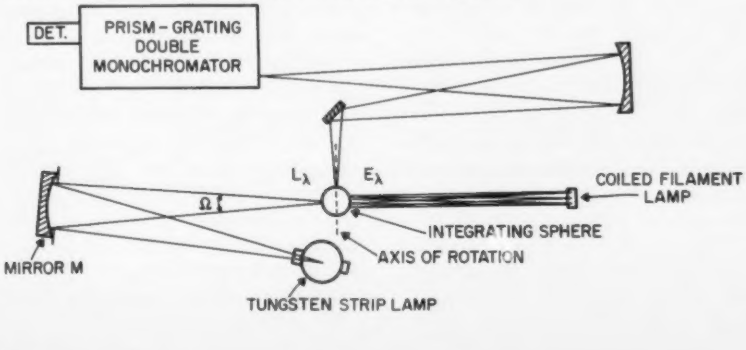
The roles of NBS and CORM in solving pressing measurement problems were discussed. Items considered were scales versus techniques, intercomparisons and the NBS Measurement Assurance Program, and documentary standards and ASTM.

A recommended organizational structure for CORM was described. Four working groups and their coordinators were identified. The Standards Groups Interface group, headed by Bob Watson of E.G. & G. would act as a standards clearing house and promote more efficient use of existing standards organizations. The CORM-NBS Interface group, led by Franc Grum of Eastman Kodak, would promote communication between NBS and the electro-optics industry, interacting technically and interpreting needs and priorities. The CORM Meetings group, headed by Ed Steeb of General Electric, would handle the mechanics of the meetings, which are expected to occur each 6 months. The Technical Projects group, led by Dick Becherer of Polaroid, would coordinate CORM participation of six C.I.E. International TC 1.2 projects (1-6 below) and four CORM projects (7-10 below). These projects and the specific CORM members heading them are:

1. Absolute reflectance of white diffusers (W. Heaps, Macbeth).
2. Characteristics of detectors (R. Walker, E.G. & G.).
3. Comparison of spectral radiometric measurements on fluorescent lamps (C. Jerome, Sylvania).
4. Monograph on spectroradiometry (R. Becherer, Polaroid).
5. Intercomparison of national scales of spectral irradiance (D. McSparron, NBS).
6. Vocabulary (R. Watson, E.G. & G.).
7. Characteristics of sources of Radiometry and Photometry (D. Mertz, ITT).
8. National laboratory services and research programs (Bruce Steiner, NBS).
9. Redefinition of Photometric System (M. Zinchuk, Polaroid).
10. Intercomparisons (F. Grum, Eastman Kodak).

The next CORM meeting is scheduled for April 1973 in Washington, D.C. The principal topic will be a review of the work being done by the many existing standards groups.

Apparatus for realizing an improved scale of spectral irradiance.



[1] Order from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, SD Catalog No. C13.46:594-4.

The Metric System

A CHANGEOVER IS UNDER WAY

Excerpts from remarks by L. E. Barbrow, National Bureau of Standards, Phoenix, Ariz., December 12, 1972.

With the metric system spreading throughout industry and throughout our school systems, all of us will eventually come to a point when we will want to become familiar with what we will need to know about metric units in our everyday lives. A maximum of 10 new words and what they mean are all you will need to know about the metric "language." I use the term "language" purposely. Whereas a new language requires learning hundreds of words, the metric language requires learning about 10 words. We have in our office a chart with the title "All You Will Need to Know About Metric (For Your Everyday Life)." It depicts the meter (1) as a little longer than the yard, the liter (2) as a little larger than the quart, the kilogram (3) as a little heavier than 2 pounds, the millimeter (4) as the diameter of paper clip wire, the centimeter (5) as not quite 1/2 inch, the kilometer (6) as somewhat further than 1/2 mile, the gram (7) as the weight of a paper clip, the milliliter (8) as 1/5 of a teaspoon, the hectare (9) as about 2 1/2 acres, and the metric tonne (10) as about equal to a customary long ton. These 10 units are really more than you will need for everyday life. In addition, you will need to know a few temperatures expressed in °C instead of in °F: water freezes at 0 °C and boils at 100 °C, body temperature is 37 °C, and a comfortable range of temperature is 20 to 25 °C (that is 68 to 77 °F).

There is no need to learn this new but simple metric language now unless you want to keep current with children learning metric at school or with workers learning metric on the job. But the time will come when the use of metric units will be so common that we will be impelled to learn some new measurement units. When that time comes, perhaps 10 years or more from now, our country will be predominately, but not exclusively, metric. We will then have attained the objective of the metric changeover recommended by the Department of Commerce and embodied in legislation likely to be enacted by the 93rd Congress.

The major purpose of this legislation is to create a mechanism for planning the transition to the metric system on a national scale. Senate Bill S.2483, passed by the Senate last session but not acted upon by the House, is an excellent basis for metric legislation to be introduced in the 93rd Congress.

I think it is important to note that metrication will proceed whether or not Laws are enacted. The use of the metric system is growing apace and will not slow down. What is the need then for legislation? Primarily, to put planning into our current haphazard approach, and secondarily, to inform the nation that in-

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UNITED STATES DEPARTMENT OF COMMERCE
PETER G. PETERSON, Secretary
NATIONAL BUREAU OF STANDARDS / LAWRENCE M. KUSHNER, Acting Director

Special Publication 304 A. Revised October, 1972

Brief History of

MEASUREMENT SYSTEMS

with a Chart of the Modernized Metric System

"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life."

JOHN QUINCY ADAMS
Report to the Congress, 1821

Weights and measures were among the earliest tools invented by man. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials.

Man understandably turned first to parts of his body and his natural surroundings for measuring instruments. Early Babylonian and Egyptian records and the Bible indicate that length was first measured with the forearm, hand, or finger and that time was measured by the periods of the sun, moon, and other heavenly bodies. When it was necessary to compare the capacities of containers such as gourds or clay or metal vessels, they were filled with plant seeds which were then counted to measure the volumes. When means for weighing were invented, seeds and stones served as standards. For instance, the "carat," still used as a unit for gems, was derived from the carob seed.

As societies evolved, weights and measures became more complex. The invention of numbering systems and the science of mathematics made it possible to create whole systems of weights and measures suited to trade and commerce, land division, taxation, or scientific research. For these more sophisticated uses it was necessary not only to weigh and measure more complex things—it was also necessary to do it accurately time after time and in different places. However, with limited international exchange of goods and communication of ideas, it is not surprising that different systems for the same purpose developed and became established in different parts of the world—even in different parts of a single continent.

The English System

The measurement system commonly used in the United States today is nearly the same as that brought by the colonists from England. These measures had their origins in a variety of cultures—Babylonian, Egyptian, Roman, Anglo-Saxon, and Norman French. The ancient "digit," "palm," "span," and "cubit" units evolved into the "inch," "foot," and "yard" through a complicated transformation not yet fully understood.

Roman contributions include the use of the number 12 as a base (our foot is divided into 12 inches) and words from which we derive many of our present weights and measures names. For example, the 12 divisions of the Roman "pes," or foot, were called *unciae*. Our words "inch" and "ounce" are both derived from that Latin word.

The "yard" as a measure of length can be traced back to the early Saxon kings. They wore a sash or girdle around the waist—that could be removed and used as a convenient measuring device. Thus the word "yard" comes from the Saxon word "gird" meaning the circumference of a person's waist.

Standardization of the various units and their combinations into a loosely related system of weights and measures sometimes occurred in fascinating ways. Tradition holds that King Henry I decreed that the yard should be the distance from the tip of his nose to the end of his thumb. The length of a furlong (or furrow-long) was established by early Tudor rulers as 220 yards. This led Queen Elizabeth I to declare, in the 16th century, that henceforth the traditional Roman mile of 5,000 feet would be replaced by one of 5,280 feet, making the mile exactly 8 furlongs and providing a convenient relationship between two previously ill-related measures.

Thus, through royal edicts, England by the 18th century had achieved a greater degree of standardization than the continental countries. The English units were well suited to commerce and trade because they had been developed and refined to meet commercial needs. Through colonization and dominance of world commerce during the 17th, 18th,

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THE MODERNIZED

metric system

The International System of Units-SI

is a modernized version of the metric system established by international agreement. It provides a logical and interconnected framework for all measurements in science, industry, and commerce. Officially abbreviated SI, the system is built upon a foundation of seven base units, plus two supplementary units, which appear on this chart along with their definitions. All other SI units are derived from these units. Multiples and submultiples are expressed in a decimal system. Use of metric weights and measures was legalized in the United States in 1866, and since 1893 the yard and pound have been defined in terms of the meter and the kilogram. The base units for time, electric current, amount of substance, and luminous intensity are the same in both the customary and metric systems.

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	[A]25.4	[B]millimeters	mm
ft	feet	[A]0.3048	meters	m
yd	yards	[A]0.9144	meters	m
mi	miles	1.609 34	kilometers	km
yd^2	square yards	0.836 127	square meters	m^2
	acres	0.404 686	[C]hectares	ha
yd^3	cubic yards	0.764 555	cubic meters	m^3
qt	quarts (lq)	0.946 353	[D]liters	l
oz	ounces (avdp)	28.349 5	grams	g
lb	pounds (avdp)	0.453 592	kilograms	kg
°F	Fahrenheit temperature	[A]5/9 (after subtracting 32)	Celsius temperature	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m^2	square meters	1.195 99	square yards	yd^2
ha	hectares	2.471 05	acres	
m^3	cubic meters	1.307 95	cubic yards	yd^3
l	[D]liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	Celsius temperature	[A]9/5 (then add 32)	Fahrenheit temperature	°F

[A] exact

[B] for example, 1 in = 25.4 mm, so 3 inches would be $(3\ in)(25.4\ \frac{mm}{in}) = 76.2\ mm$

[C] hectare is a common name for 10 000 square meters

[D] liter is a common name for fluid volume of 0.001 cubic meter

Note: Most symbols are written with lower case letters; exceptions are units named after persons for which the symbols are capitalized. Periods are not used with any symbol.

Multiples and Submultiples	Prefixes	Symbols
[illegible] = 10	tera [illegible]	T
1 000 000 000 = 10	giga [illegible]	G
1 000 000 = 10	mega [illegible]	M
1 000 = 10	kilo [illegible]	k
100 = 10	hecto [illegible]	h
10 = 10	deka [illegible]	da
Base unit 1 = 10		
0.1 = 10	deci [illegible]	d
0.01 = 10	centi [illegible]	c
0.001 = 10	milli [illegible]	m
0.000 001 = 10	micro [illegible]	μ
[illegible] = 10	nano [illegible]	n
0.000 000 000 001 = 10	pico [illegible]	p
[illegible] = 10	femto [illegible]	f
[illegible] = 10	atto [illegible]	a

National Bureau of Standards
Special Publication 304A Revised October 1972

meter-m
LENGTH

kilogram-kg

second-s
TIME

ampere-A
ELECTRIC CURRENT

kelvin-K
TEMPERATURE

The kelvin is defined ... tion 1/273.16 of the ... namic temperature ... point of water. The ... 0 K is called "absolu...

mole-mol
AMOUNT OF SUBSTANC...

candela-cd
LUMINOUS INTENSITY

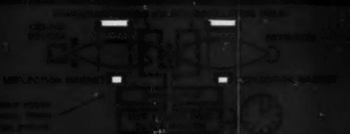
radian-rad
PLANE ANGLE

The radian is the pl... vertex at the center ... subtended by an arc ... the radius.

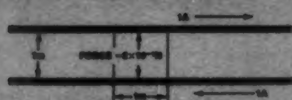
A full-scale wall chart, NBS Special Publication 304 (Revised October 1972,) is available from the Super...

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

SEVEN BASE UNITS



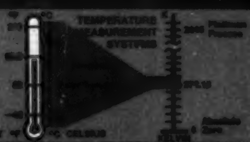
...ampere is defined as that current which, if maintained in each of two ... parallel wires separated by one meter in free space, would produce ...rce between the two wires (due to their magnetic fields) of 2×10^{-7} ...ton for each meter of length.



The SI unit of voltage is the volt (V).
$1V = 1W/A$

The SI unit of electric resistance is the ohm (Ω).
$1\Omega = 1V/A$

...as the frac- ... thermody- ...f the triple ...mperature ...e zero"



On the commonly used Celsius temperature scale, water freezes at about 0 °C and boils at about 100 °C. The °C is defined as an interval of 1 K, and the Celsius temperature 0 °C is defined as 273.15 K.

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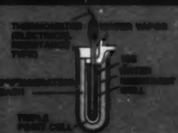
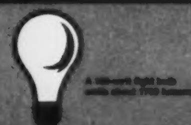


The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a blackbody at the temperature of freezing platinum (2045 K).

The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4 π lumens.

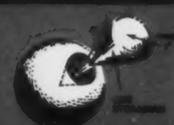


TWO SUPPLEMENTARY UNITS

...ne angle with its ...of a circle that is ...equal in length to

steradian-sr
SOLID ANGLE

The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of the spherical surface equal to that of a square with sides equal in length to the radius.



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1 000 000 000 000 =	10^{12}	tera (tĕr′a)	T
1 000 000 000 =	10^{9}	giga (jĭ′ga)	G
1 000 000 =	10^{6}	mega (mĕg′a)	M
1 000 =	10^{3}	kilo (kĭl′ō)	k
100 =	10^{2}	hecto (hĕk′tō)	h
10 =	10^{1}	deka (dĕk′a)	da
Base Unit 1 =	10^{0}		
0.1 =	10^{-1}	deci (dĕs′ĭ)	d
0.01 =	10^{-2}	centi (sĕn′tĭ)	c
0.001 =	10^{-3}	milli (mĭl′ĭ)	m
0.000 001 =	10^{-6}	micro (mī′krō)	μ
0.000 000 001 =	10^{-9}	nano (năn′ō)	n
0.000 000 000 001 =	10^{-12}	pico (pē′kō)	p
0.000 000 000 000 001 =	10^{-15}	femto (fĕm′tō)	f
0.000 000 000 000 000 001 =	10^{-18}	atto (ăt′tō)	a

National Bureau of Standards
Special Publication 304A (Revised October 1972)
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SD Catalog No. C13.10:304A – Price 25 cents

REFERENCES

NBS Special Publication 330, 1972 Edition, International System of Units (SI), available by purchase from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, order as C13.10:330/2, 30 cents a copy.

ASTM Metric Practice Guide E380-72, available by purchase from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103 – $1.50 a copy, minimum order $3.00.

Rules for the Use of Units of the International System of Units, order as ISO Recommendation R1000, $1.25 a copy from the American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

meter-m
LENGTH

The meter (common in... is defined as 1 650 763... the orange-red line of...

kilogram-kg
MASS

second-s
TIME

The second is defined... cycles of the radiation... transition of the cesium... tuning an oscillator... cesium-133 atoms... magnets and a res...

ELECTRIC CURRENT

The... long... a for... newt...

kelvin-K
TEMPERATURE

The kelvin is defined a... tion 1/273.16 of the... namic temperature of... point of water. The te... 0 K is called "absolute...

mole-mol
AMOUNT OF SUBSTANCE

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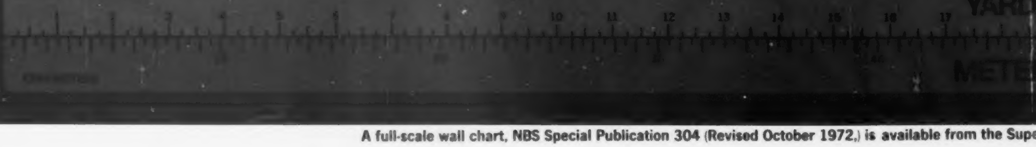
radian-rad
PLANE ANGLE

The radian is the pla... vertex at the center... subtended by an arc... the radius.



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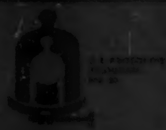
U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

SEVEN BASE UNITS

...ternational spelling, metre) ...73 wavelengths in vacuum of ...e spectrum of krypton-86.

The SI unit of area is the square meter (m^2).

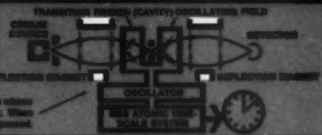
The SI unit of volume is the cubic meter (m^3). The liter (0.001 cubic meter), although not an SI unit, is commonly used to measure fluid volume.



The SI unit of force is the newton (N). One newton is the force which, when applied to a 1 kilogram mass, will give the kilogram mass an acceleration of 1 (meter per second) per second.

$1N = 1kg{\cdot}m/s^2$

...s the duration of 9 192 631 770 ...n associated with a specified ...m-133 atom. It is realized by ...o the resonance frequency of ...they pass through a system of ...nt cavity into a detector.



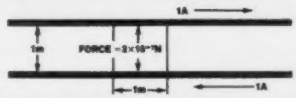
The number of periods or cycles per second is called frequency. The SI unit for frequency is the hertz (Hz). One hertz equals one cycle per second.

The SI unit for speed is the meter per second (m/s).

The SI unit for acceleration is the (meter per second) per second (m/s^2).

Standard frequencies and correct time are broadcast from WWV, WWVB, and WWVH, and stations of the U.S. Navy. Many shortwave receivers pick up WWV and WWVH, on frequencies of 2.5, 5, 10, 15, and 20 megahertz.

...ampere is defined as that current which, if maintained in each of two ...parallel wires separated by one meter in free space, would produce ...ce between the two wires (due to their magnetic fields) of 2×10^{-7} ...on for each meter of length.



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$1V = 1W/A$

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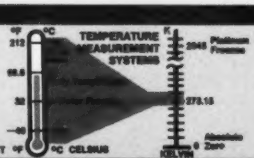
$1\Omega = 1V/A$

...s the frac- ...thermody- ...f the triple ...mperature ...e zero"



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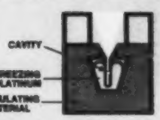
The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the mole per cubic meter (mol/m^3).

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a blackbody at the temperature of freezing platinum (2045 K).



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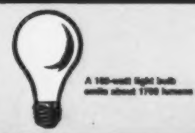
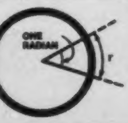


TWO SUPPLEMENTARY UNITS

...ne angle with its ...of a circle that is ...equal in length to



steradian-sr
SOLID ANGLE

The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of the spherical surface equal to that of a square with sides equal in length to the radius.

...rintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, for 55 cents.

and 19th centuries, the English system of weights and measures was spread to and established in many parts of the world, including the American colonies.

However, standards still differed to an extent undesirable for commerce among the 12 colonies. The need for greater uniformity led to clauses in the Articles of Confederation (ratified by the original colonies in 1781) and the Constitution of the United States (ratified in 1790) giving power to the Congress to fix uniform standards for weights and measures. Today, standards supplied to all the States by the National Bureau of Standards assure uniformity throughout the country.

The Metric System

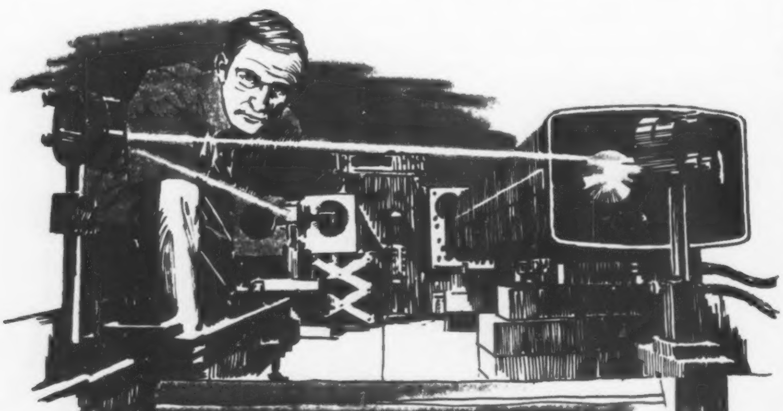
The need for a single worldwide coordinated measurement system was recognized over 300 years ago. Gabriel Mouton, Vicar of St. Paul in Lyons, proposed in 1670 a comprehensive decimal measurement system based on the length of one minute of arc of a great circle of the earth. In 1671 Jean Picard, a French astronomer, proposed the length of a pendulum beating seconds as the unit of length. (Such a pendulum would have been fairly easily reproducible, thus facilitating the widespread distribution of uniform standards.) Other proposals were made, but over a century elapsed before any action was taken.

In 1790, in the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights." The Commission appointed by the Academy created a system that was, at once, simple and scientific. The unit of length was to be a portion of the earth's circumference. Measures for capacity (volume) and mass (weight) were to be derived from the unit of length, thus relating the basic units of the system to each other and to nature. Furthermore, the larger and smaller versions of each unit were to be created by multiplying or dividing the basic units by 10 and its multiples. This feature provided a great convenience to users of the system, by eliminating the need for such calculations as dividing by 16 (to convert ounces to pounds) or by 12 (to convert inches to feet). Similar calculations in the metric system could be performed simply by shifting the decimal point. Thus the metric system is a "base-10" or "decimal" system.

The Commission assigned the name *metre* (which we now spell meter) to the unit of length. This name was derived from the Greek word *metron*, meaning "a measure." The physical standard representing the meter was to be constructed so that it would equal one ten-millionth of the distance from the north pole to the equator along the meridian of the earth running near Dunkirk in France and Barcelona in Spain.

The metric unit of mass, called the "gram," was defined as the mass of one cubic centimeter (a cube that is 1/100 of a meter on each side) of water at its temperature of maximum density. The cubic decimeter (a cube 1/10 of a meter on each side) was chosen as the unit of fluid capacity. This measure was given the name "liter."

Although the metric system was not accepted with enthusiasm at first, adoption by other nations occurred steadily after France made its use compulsory in 1840. The standardized character and decimal features of the metric system made it well suited to scientific and engineering work. Consequently, it is not surprising that the rapid spread of the system coincided with an age of rapid technological development. In the United States, by Act of Congress in 1866, it was made "lawful throughout the United States of America to employ the weights and measures of the metric system in all contracts, dealings or court proceedings."



By the late 1860's, even better metric standards were needed to keep pace with scientific advances. In 1875, an international treaty, the "Treaty of the Meter," set up well-defined metric standards for length and mass, and established permanent machinery to recommend and adopt further refinements in the metric system. This treaty, known as the Metric Convention, was signed by 17 countries, including the United States.

As a result of the Treaty, metric standards were constructed and distributed to each nation that ratified the Convention. Since 1893, the internationally agreed-to metric standards have served as the fundamental weights and measures standards of the United States.

By 1900 a total of 35 nations—including the major nations of continental Europe and most of South America—had officially accepted the metric system. Today, with the exception of the United States and a few small countries, the entire world is using predominantly the metric system or is committed to such use. In 1971 the Secretary of Commerce, in transmitting to Congress the results of a 3-year study authorized by the Metric Study Act of 1968, recommended that the U.S. change to predominant use of the metric system through a coordinated national program. The Congress is now considering this recommendation.

The International Bureau of Weights and Measures located at Sevres, France, serves as a permanent secretariat for the Metric Convention, coordinating the exchange of information about the use and refinement of the metric system. As measurement science develops more precise and easily reproducible ways of defining the measurement units, the General Conference of Weights and Measures—the diplomatic organization made up of adherents to the Convention—meets periodically to ratify improvements in the system and the standards.

In 1960, the General Conference adopted an extensive revision and simplification of the system. The name *Le Système International d'Unités* (International System of Units), with the international abbreviation SI, was adopted for this modernized metric system. Further improvements in and additions to SI were made by the General Conference in 1964, 1968, and 1971.

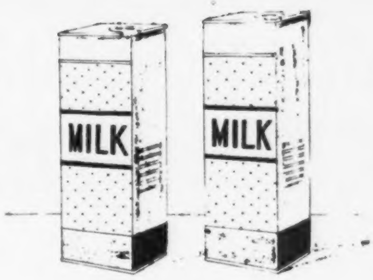
☆ U.S. GOVERNMENT PRINTING OFFICE : 1972 O - 488-984

creasing metric use is officially deemed to be in its best interests and in accord with national policy.

The whisper of the metric wind is becoming louder as more and more companies announce their policy to change over. With industry making known the increasing need for people who know metric units, educators have been alerted to the need to train youngsters in metric usage in order to prepare them for the business world. The Office of Education and the National Science Foundation are cooperating with NBS in assessing national needs for metric education and developing approaches and resources to meet them; e.g., curricula, educational materials, and their dissemination throughout the educational systems of the country. NBS will provide technical support, particularly by screening books and materials for technical errors.

One should not belittle the magnitude of the metrication process. To the extent we use weights and measures, we will all have to learn to "think metric." We must also face, and help minimize, the confusion of transition. The need for retraining workers and the eventual obsolescence of worker-owned tools form the basis of union opposition to "going metric." These legitimate concerns can be resolved as they have been resolved by the British in changing over to the metric system. Worker retraining and replacement of worker-owned tools have been handled successfully by collective bargaining in the past. There is no doubt that they can successfully be handled in the future. An important consideration is that many U.S. companies making metric products have found it advantageous to build abroad, using workers who know the metric system. A national changeover to the metric system might help halt the "export" of such jobs.

A change in the customary measurement language of America can-



not be performed by the Government. This can be accomplished only by the cooperation of consumers, workers, business men and women, teachers, engineers, and all other sectors of our national life. Just as industry should plan for metrication in industry, so should home economists plan metrication for the home, and educators in the schools. Widespread cooperation can be obtained only by means of a well planned, coordinated national metrication program, as embodied in the aforementioned legislation.

In the current changeover to metric measurements, four key principles are being followed carefully:

(1) The rule of reason—changes to metric should be made only where it is advantageous. No area should change "at any cost," but neither should any area refrain from changing "at any cost."

(2) Costs lie where they fall—this principle is a corollary of principle (1). It seems entirely reasonable that costs should lie where they fall if for no other reason than to assure that the costs themselves will be reasonable and commensurate with benefits. Stated somewhat differently this principle states that the cost will fall on him who benefits.

(3) Voluntary changeover—this principle is a corollary of principle (2); with costs lying where they fall, they cannot be imposed. The changeover must not be mandatory.

(4) Nongovernmental initiative—this principle is a corollary of principle (3); as long as the initiative and planning are in the private sector there is little chance that the changeover would be anything but voluntary. Government, of course, will play in important role because it is a significant sector of our society. We envision that all sectors will be involved in planning and in the metric changeover.

England is now two-thirds of the way through a 10-year metrication program. A close friend of mine sent me this somewhat contrived poem from the Autumn 1972 issue of This England:

Metrication—a lament

Farewell to ounce and pound and stone,
Gill, pint, quart, gallon too are gone.
No link, no chain, no furlong now,
No more "3 acres and a cow."
Gone are the feet, the yards, the roods,
No peck, no bushel for our goods.
How pleased I was, in days of yore, to have on chart nine eight point four.
And see forecasted, with delight,
"Temp. about 70° Fahrenheit".
Now all forecasting must be made,
In unconvertible Centigrade.
Subtracting this—by that divide?
The answer I can ne'er decide.
To what dull outlook we're reduced,
Now metrication's introduced.
Milli—Centi—Kilometres,
Or, if it's bulk in grammes and litres.
A hundred lovely words all gone,
Banished from out the English Tongue.
What? Do you think it is absurd,
To mourn the loss of ancient word?
Or queer that one should seem to treasure,
Old scales of weight, old ways of measure?
Remember friend, it is the word,
That marks us out from Beast and Bird.
Should we not keep our language least,
We grow yet nearer to the Beast?

This is a needless lament. We shall indeed keep our customary language, and not only in poetry and in priceless quotations. Changing to metric will not *displace* "mile," "furlong," and "yard," except for cause. We hope the rule of reason will preclude any cause to lament. Instead, the changeover affords an opportunity to enrich our language while improving our technology and reaping the rewards that international harmonization of measurement language and engineering standards can bestow on us.

NBS HELPS WITH PROBLEMS OF WASTE INCINERATION

Industrial incinerators that burn cleaner and last longer could result from recent work by the Bureau. NBS scientists have compiled, in field handbook form, readily usable thermodynamic data on likely incinerator reactants and products. These data will enable engineers to design incinerators better for burning industrial wastes.

NEED FOR THERMODYNAMIC DATA

The American Society of Mechanical Engineers (ASME) recognized an urgent need to provide the engineering community with more readily-accessible thermodynamic information, and approached NBS for help. The Bureau's Office of Standard Reference Data and Physical Chemistry Division have collaborated with ASME's Research Committee on Industrial Wastes to produce a compilation of thermodynamic data on potential incinerator ingredients and products of combustion. This collaborative effort will be published as an ASME monograph as Part II of a two-part effort. This compilation, Part II The Scientific Approach: "Thermodynamic Data for Industrial Incinerators with Guides to the Use of the Tables," was authored by NBS's Drs. George T. Armstrong and Eugene S. Domalski,[1] and has appeared in preliminary form as a final technical report.

ASME's Part I of the two-part monograph, "The Engineering Approach," is being prepared by Elmer S. Monroe, Jr. (E.I. du Pont de Nemours and Co., Inc.), a member of ASME's Research Committee on Industrial Wastes.

INCINERATOR DESIGN AND OPERATION

In the design and operation of incinerators the engineer must solve two important problems. The first has several parts:

- The engineer must determine the waste material composition.
- He must analyze the main ingredients or reactants (input materials) and must also know if auxiliary combustion aids should be present. If undesirable effluents are to be avoided, the engineer must adequately characterize the waste material to be burned, must know how to properly introduce it into the incinerator, and must know how this material should respond to any required operating adjustments.

The second problem the engineer must solve is determining the heat balance of the combustion process to maintain correct temperature control. Satisfactory solution of these two problems in a mutually consistent way requires pertinent thermodynamic data readily accessible to the engineer for necessary calculations.

TABULATION PRIORITIES

As a first step toward preparing the ASME monograph, Wayman L. Calhoun (Union Carbide Corp.) of the ASME Research Committee made a survey whose purpose was to provide a basic list of substances for inclusion in the thermodynamic data compilation. Those queried were primarily members of the ASME Subcommittee on Coordination with Associations and Government. Results of this preliminary survey disclosed the following facts:

- Organic materials make up large fractions of industrial wastes and they generally fall into three categories: Well defined pure substances, organic materials of variable composition, but resolvable into known components, and poorly defined mixtures.
- There are more *organic* than *inorganic* wastes. Inorganic ingredients include essentially all the elements in small amounts, but some inorganics, such as ferrous and nonferrous metals, make up relatively large quantities of waste material.

Based on the survey, available manpower, time and effort, and the desire to publish (in a reasonably short time) useful and important design information, priorities for compiling subject material were decided. Enthalpy (heat) of formation

at 25 °C (298.15 K) was chosen as the property most useful for this compilation, with most of the values being selected from recent careful reviews largely done at NBS.

Existing tables of thermodynamic functions are available for many of the important substances in the extensive JANAF* Thermochemical Tables and their associated computer tapes. Therefore, the scope of coverage in the compilation consisted of the following for which experimental data are available: well-characterized organic compounds and inorganic carbon compounds, organic polymers to which a reasonably good formula could be assigned, and inorganic oxides.

*JANAF is an acronym for: Joint Army, Navy, Air Force.

The NBS compilation contains tabulated thermodynamic data for over 1,300 substances needed by engineers for designing and operating industrial waste incinerators. In addition to the tables, definitions of thermodynamic terms and discussions of thermodynamic calculations are included.

MONOGRAPH'S IMPORTANCE

It is possible for an engineer to anticipate the presence of certain products of a combustion process because of specific conditions. For example, the composition of combustion products depends upon the elements present in the material undergoing reaction. The physical state of combustion products (gas, liquid, or solid) depends upon the temperatures and partial pressures of the substances at the end of the process. Whether the reaction is carried out under constant-volume or constant-pressure conditions, or in the presence or absence of water, also influences the kind and physical state of combustion products.

This NBS work for the first time brings to incinerator engineers readily available thermodynamic data in useful handbook form. Heretofore much of this data appeared in nonengineering publica-

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NSRDS NEWS

The NSRDS was established to make critically evaluated data in the physical sciences available to science and technology on a national basis. The NSRDS is administered and coordinated by the NBS Office of Standard Reference Data.

REPORT ON CURRENT STATUS OF THE NSRDS

NBS Technical Note 747, *Critical Evaluation of Data in the Physical Sciences—A Status Report on the National Standard Reference Data System, June 1972*, Stephen A. Rossmassler (Editor)[1] (SD Catalog No. C13.46:747, $1.25), is now available. The NSRDS program was established in 1963 under the general enabling legislation of the National Bureau of Standards. In 1968, Congress provided specific legislative authority for the program through passage of Public Law 90-396, the Standard Reference Data Act. The major aim of the program is to provide critically evaluated numerical data to the technical community in a convenient, accessible form. A second but equally important aim of the NSRDS program has been to provide feedback into the generation of physical data that can raise the general standards of measurement; that is, by communicating the experience gained in evaluating the world output of data in the physical sciences, it is believed that experimental techniques can be advanced and the reliability of physical measurements improved.

The technical scope of the NSRDS program is restricted to well-defined physical and chemical properties of substances and systems that are well characterized. Biological properties and data relating to large, natural systems fall out of the scope of the program, as do properties that depend on arbitrarily defined characteristics of measurement techniques. The scope of the NSRDS encompasses seven technical areas: thermodynamics and transport properties, atomic and molecular data, chemical kinetics, solid state data, nuclear data, colloid and surface properties, and mechanical properties.

NBS Technical Note 747 details the status of the program as of June 1972, providing information on the progress of activities in each of the seven technical areas as well as of data system design activities and information services. A progress report is provided for each data evaluation project supported fully or in part by the Office of Standard Reference Data (OSRD), the management vehicle for the NSRDS. Included are both short-term projects and continuing data centers. A complete list of continuing data centers in the United States that are recognized as part of the national effort in the NSRDS program is given in an Appendix. The report also provides a full list of publications that have appeared under the auspices of the NSRDS. There are now 50 titles in the formal NSRDS series; in addition, approximately 70 other data compilations, bibliographies, and translations have appeared.

In 1971, the OSRD began exploration of alternate publication procedures which would make use of the authority granted it in the Standard Reference Data Act and be responsive to the intentions of Congress in granting it. As a result, a periodical is now being produced with the active collaboration of the American Chemical Society and the American Institute of Physics. The first issue of the quarterly *Journal of Physical and Chemical Reference Data* appeared in March 1972. The major compilations of physical and chemical property data of the program are now published in the Journal. The Journal is also open to contributions of acceptable quality and scope from other sources. Longer data compilations, which would overcrowd the regular issues, will appear as *Supplements* to the *Journal of Physical and Chemical Reference Data*. Copies of individual compilations and reviews appearing in the Journal are available for separate purchase.[2]

THERMOPHYSICAL PROPERTIES OF HELIUM 4 FROM 4 TO 3,000 R WITH PRESSURES TO 15,000 PSI

NBS Technical Note 622, *Thermophysical Properties of Helium 4 from 4 to 3,000 R with Pressures to 15,000 PSIA* by Robert D. McCarty[1] (SD Catalog No. C13.46:622, $1.25), contains data on many of the properties of helium commonly used in engineering calculations, and covers as wide a temperature and pressure range as is practical. Each table of values has been critically evaluated and represents the "best value" available at this time.

Helium 4 properties have been of great interest to science and engineering for years, but much of the work has been devoted to the more spectacular properties of helium II, the superfluid phase. These tables do not include superfluid properties, except for the pressure-density-temperature table where the transition to superfluidity begins. Isobaric tables include entropy, enthalpy, internal energy, density, volume, speed of sound, specific heat, thermal conductivity, viscosity, thermal diffusivity, Prandtl number and the dielectric constant, plus tables of quantities of special utility in heat transfer calculations. There are also tables of the above properties (and one of surface tension) for the saturated vapor and liquid stages, and for various other properties such as index of refraction and Joule-Thomson curve.

SYMPOSIUM ON MAN-MACHINE COMMUNICATION FOR SCIENTIFIC DATA HANDLING

The Task Group on Computer Use of the ICSU Committee on Data for Science and Technology (CODATA) will hold a symposium at the University of Freiburg, Freiburg-im-Breisgau, Germany, from July 22d to 27th, 1973.

The purpose of the symposium is to bring together specialists concerned with the application of computer technology to the compilation, storage, and utilization of quantitative scientific data in the physical, biological, geological, and engineering sciences.

The symposium will be patterned on the Gordon Research Conferences, centering around a series of invited lectures with opportunities provided for small groups to deal collectively with areas of specialized interests in working seminars.

Attendance will be by invitation; interested organizations and individuals are requested to write without delay to the Secretary of the Task Group, c/o Mr. M. K. Ward, International Conferences Office, National Research Council of Canada, Ottawa K1A OR6, Canada, including a brief statement of their areas of special interest.

U.S. NUCLEAR DATA COMMITTEE

A U.S. Nuclear Data Committee (USNDC) has recently been established under the auspices of the Director of Physical Research of the Atomic Energy Commission in cooperation with the National Standard Reference Data System of NBS. This Committee is concerned with the problems of measurement, compilation, evaluation, and dissemination of nuclear data for basic and applied nuclear sciences and technology. This Committee evolved from the Nuclear Cross Sections Advisory Committee to the Atomic Energy Commission in order to meet the developing needs for basic nuclear science, fusion reactors, nuclear safeguards, biomedical applications and the environmental sciences. It also serves as an interface with two international groups: the European-American Nuclear Data Committee (E-ANDC), operating under the auspices of the Nuclear Energy Agency (NEA), and the International Nuclear Data Committee (INDC), which operates under the auspices of the International Atomic Energy Agency (IAEA).

One of the important functions of the USNDC is to consider requests for nuclear data measurements and to disseminate, on a periodic basis, lists of nuclear data needs to the community of nuclear data measurers. Another important function is to distribute to interested parties reports on the status of nuclear data measurements, especially as they pertain to the request list.

People working in areas where a need exists for the best available nuclear data are urged to contact the Nuclear Data Project, Oak Ridge National Laboratory (for nuclear structure and reaction data) or the National Neutron Cross Section Center, Brookhaven National Laboratory (for neutron data). Requests for other types of data or for general information on nuclear data collections may be addressed to the Office of Standard Reference Data, National Bureau of Standards, Washington, D.C. 20234.

Should the required data be unobtainable and should the need be such as to require new measurement activity, the requester is urged to make his needs known to the USNDC through the Office of the Director of Physical Research, U.S. Atomic Energy Commission, Washington, D.C. 20545.

SUMMER COURSE ON DATA EVALUATION

Under the leadership and planning of the Education Committee of the Numerical Data Advisory Board—the advisory panel of the Office of Standard Reference Data—of the National Academy of Sciences, National Academy of Engineering, and National Research Council, a week long course on the process of numerical data evaluation has been instituted at Pennsylvania State University with financial support from the National Science Foundation. The course is designed to provide college physical science teachers with an un-

derstanding and appreciation of the critical evaluation of data. The purpose is to enable teachers to include data analysis as an integral part of undergraduate courses. Subject matter will be divided into five areas: importance of critically evaluated data, treatment of experimental data, presentation of data in the primary literature, process of critical evaluation of data, and sources of critically evaluated data. A distinguished panel of speakers will provide instruction. The course is scheduled for June 24-30, 1973. Participants selected for the course will receive a stipend and travel support. Requests for more detailed information and application for admittance should be sent to:

Dr. G. G. Johnson, Jr.
Director, NSF Short Course
The Pennsylvania State University
University Park, Pa. 16802
Phone: (814) 865-1637

ROCK PROPERTIES INFORMATION CENTER ESTABLISHED AT TPRC

A program specializing in the properties of geological substances was established at the Thermophysical Properties Research Center (TPRC), Purdue University, in June 1972 under a grant from the National Science Foundation (NSF-RANN). The program constitutes an interdisciplinary effort involving major investigators from three University departments: Professor W. R. Judd (Rock Mechanics), Civil Engineering; Professor T. R. West, Geosciences; and Professor D. P. DeWitt, Mechanical Engineering and TPRC. The goal is to develop a center which can provide quick response to technical and bibliographic inquiries, generate recommended reference data, and perform relevant experimental research much in the same pattern as TPRC has performed in its area of specialization.

This new program has four major activity areas. One project is concerned with the generation of data tables for the mechanical, physical, and thermal properties of minerals and rocks; particularly important is the inclusion of sufficient sample characterization and test conditions to permit correlations. Another goal of the program is to organize the unclassified literature on nuclear blast/explosion phenomena for parametric studies; the effort is to identify all information relating to the response of earth media plus rock types associated with nuclear blasts. The third area of activity deals with the organization of the literature on rapid excavation and tunneling; the objective is to provide information on techniques, rock formations, geographic locations, cost and other pertient variables in support of research and development in this field. The companion experimental program has the objective to develop or refine theories of heat conduction in rocks and to correlate thermal and mechanical properties of rocks which have been petrographically characterized.

TPRC's thermophysical data evaluation activities are associated with the National Standard Reference Data System.

MÖSSBAUER EFFECT DATA INDEX

Mössbauer Effect Data Index Covering the 1971 Literature, edited by John G. Stevens and Virginia E. Stevens, is the latest volume in the annual index series. This newest volume includes 940 entries, with over 1,100 readily accessible references and information on more than 2,900 absorber-source combinations. Four convenient sections include: instructions on how to use the index; papers on related topics; equipment, sources, and supplies; and tables and graphs.

The Mössbauer Effect Data Index, which was supported in part by the Office of Standard Reference Data, may be purchased from the Plenum Publishing Corp., 227 West 17th Street, New York, N.Y. 10011, for $32.50 to institutions and $25 to individuals.

RAMAN SPECTRA

Sadtler Research Laboratories, Inc., of Philadelphia, has announced the publication of a new continuing collection of Raman reference spectra. The initial publication consists of three volumes and contains Raman and infrared grating spectra of 1,200 compounds. The spectra are presented in a format based on recommendations for the presentation of Raman spectra by the Commission on Molecular Structure and Spectroscopy of the Physical Chemistry Division of the International Union of Pure and Applied Chemistry (IUPAC). Liquid samples are represented by an infrared grating and a perpendicular and a parallel polarized Raman spectrum, while solid samples are represented by an IR grating and a nonpolarized Raman spectrum. Each spectrum contains pertinent information about the compound and the instrumental parameters.

The first 2,000 compounds in the collection will be systematically grouped into approximately 50 chemical classes. Many simple compounds are included in each class to illustrate typical characteristics. Additional spectra will be published at the rate of 2,000 compounds per year and will be available on an annual subscription basis. The collection is comprehensively indexed to facilitate rapid retrieval of spectral data.

For further information about this collection or other Sadtler Reference Spectra Libraries, please address inquiries to Sadtler Research Laboratories, Inc., 3316 Spring Garden Street, Philadelphia, Pa. 19104, or telephone (215) 382-7800.

[1] Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, for the price indicated.

[2] Available from the American Chemical Society, 1155 16th Street NW., Washington, D.C. 20036.

OIML MEETING

The International Organization of Legal Metrology (OIML) was founded in 1955 to promote international cooperation and harmonization on the legal aspects of measurement—as, for example, what measurements and measuring instruments are used in the enforcement of weights and measures laws in the marketplace. It recommends uniform international requirements for measuring instruments and works out model laws for consideration by member States.

In August 1972 the Senate approved U.S. membership in OIML, and in September the United States became the 38th member nation of OIML.

In recommending U.S. membership, President Nixon said "As the world's largest trading nation, and as a world leader in the standards field, we would be better able to assume a positive role in the setting of international standards for measurement and, in so doing, expand our international trade."

This view was reinforced by Richard Simpson, Acting Assistant Secretary of Commerce for Science and Technology. On nominating Dr. Lawrence Kushner of NBS to head the first U.S. Delegation to the International Conference of OIML, Mr. Simpson noted that, "Because the United States has not been a member, the recommendations of OIML have often ignored U.S. technology in measuring instrumentation. This has made it more difficult to sell U.S. made instruments abroad. The value of instruments which could be affected by OIML recommendations runs to $400 million annually—about half of the total instruments sold overseas each year."

LONDON CONFERENCE

Dr. Kushner, William Andrus, and Thomas Stabler of NBS, Wallace Seward of the American Petroleum Institute, and Walter Young of the Howe-Richardson Scale Company attended the 4th International Conference of Legal Metrology in London, October 23-28, 1972.

The U.S. Delegation actively participated in Conference proceedings. For example, Dr. Kushner was named a Vice President of the Conference, and Mr. Andrus was appointed to serve on the International Committee, the working body of the organization. The delegation also participated fully in Conference deliberations and actions on a wide variety of topics including technical recommendations, publications, and assistance to developing countries.

"MORALLY OBLIGATED"

Metrology becomes legal metrology when it is related to the enforcement by governments of laws establishing standards in these areas. OIML does not attempt to make international laws governing weights and measures; it recommends specific actions in this field to member nations. Under Article VIII of the organization's constitution member governments "shall be morally obligated to implement these decisions as far as possible." The question of moral obligation was addressed by Dr. Kushner at the Conference.

"It is the U.S. view that the main purpose of OIML, expressed in simple terms, is to assure that those regulations of its member governments which involve metrological matters shall be in harmony. I would urge the Conference to recognize that countries vary widely in the extent to which metrological matters are the concern of government, particularly as one considers fields of metrology far removed from traditional weights and measures. Thus, since governments which belong to OIML are 'morally obliged' to use its recommendations, it is essential that OIML consider only those areas of metrology for which its member governments can, in fact, accept the moral obligation. If OIML adopts recommendations which its member governments cannot accept as morally obligatory because they deal with subjects that are not governmental matters in those countries, then I am afraid that the concept of 'moral obligation' will become seriously eroded and compromised over a period of time."

Dr. Kushner also spoke to the question of performance versus design specifications.

"The United States recognizes the wide variance in the technological development of metrology among the OIML member states. In those countries in which metrological technology is less well developed, design specifications are most useful—and perhaps the only practical approach. But such specifications, applied in those countries whose metrological technology is more highly developed, can be undesirably restrictive and inhibiting. One possible avenue of approach, which is apparently already being taken by some OIML working groups and if so is to be encouraged, is to draft recommendations the first sections of which deal with the subject matter in terms of the desired per-

formance and subsequent sections of which provide examples of design specifications which will meet the prescribed performance."

RECOMMENDATIONS

A number of international recommendations have been approved in the past by OIML, such as on cylindrical weights from 1 g to 10 kg and rectangular weights from 5 to 50 kg; clinical thermometers, liquid meters other than water, hardness reference blocks (Brinell, Vickers, Rockwell), optical pyrometers, and manometers. At the October Conference recommendations were adopted on such items as tire pressure gages, gas meters, taximeters, polarimetric saccharimeters, medical syringes, and others.

Now that the U.S. is a member of OIML, it will have the opportunity to comment on and vote on each proposed International Recommendation. This voting is a two-step process. William Andrus, the U.S. representative on the International Committee, casts a vote on each Recommendation. If 4/5 of the Committee (each nation has one vote) votes "yes," then the Recommendation comes before the next Conference for final approval, with each delegation having one vote.

The first Recommendation up for Committee voting since the United States joined OIML is now in hand. The Recommendation, "Legal Units of Measurement," is of vast importance, as in other nations such items as medical thermometers, syringes, and other common items are considered legal measures employing "legal units." In order to base his vote on as representative an input as possible, Mr. Andrus solicited the views of manufacturers, industry associations, and weights and measures officials.

OIML STRUCTURE

Organizationally, the OIML is divided into three parts: the International Conference of Legal Metrology, which meets at least every six years (next meeting is scheduled for 1976); the International Committee of Legal Metrology, within whose framework the technical work of the organization is conducted by the working groups; and the International Bureau of Legal Metrology, which constitutes the Secretariat of the Organization.

The International Bureau has headquarters in Paris, and a staff of seven persons. Its current Director, M. Costamagna of France, will resign in 1974. Bernard Athané, 32, of France, was elected by the Conference to be his successor.

CITY GAMES *continued*

the mayor had much fence-mending to do.

Some rounds of the game will show positive and negative results, but by the end of play it becomes clear to everyone whether or not their decisions, if put into everyday practice, would probably head the city toward healthy growth or toward disaster.

CITY GAMES can be played at low cost by any group having access to large computer facilities and the capability for operating large computer programs.

The computer program tape and associated player and program manuals will soon be made available at cost. Information can be obtained by contacting Mr. John Moriarty, National Bureau of Standards, Washington, D.C. 20234, or phone (301) 921-3561.

INCINERATION *continued*

tions. Now engineers can calculate and predict industrial incineration products with greater confidence than before.

The significance of this ASME monograph lies in the increased capability it gives the industrial community for compliance with recent mandates to reduce undesirable effluents.

DATA SOURCES

Tabulated values of enthalpies of formation were obtained from the following sources: (1) selected values of heats of combustion and formation of 719 organic compounds containing the elements C, H, N, O, P, and S which were recently critically evaluated and tabulated by Domalski,[2] (2) data on organic halogen compounds, organometallic compounds, and metal salts of organic acids which were evaluated and tabulated by Wagman, Evans, Parker, et al., in NBS Technical Notes 270 series,[3-6] and (3) data on hydrocarbon compounds which were taken from the publication compiled by Rossini et al.,[7] used with minor adjustments.

Though still more thermodynamic data pertinent to industrial incineration must be gathered, evaluated, and made available, the publishing of "Thermodynamic Data for Industrial Incinerators" contributes directly and, in some cases, immediately toward helping this Nation's attack on its air pollution problems.

[1] Armstrong, G. T., and Domalski, E. S., Part II. The Scientific Approach. Thermodynamic Data for Industrial Incinerators with Guides to the Use of the Tables, Thermodynamics of Incinerator Processes (ASME Publication, in preparation).

[2] Domalski, E. S., Selected values of heats of combustion and heats of formation of organic compounds containing the elements C, H, N, O, P, and S, J. Phys. and Chem. Ref. Data **1**, 221-277 (1972).

[3] Wagman, D. D., et al., Selected Values of Chemical Thermodynamic Properties, Nat. Bur. Stand. (U.S.), Tech. Note 270-3, 264 pages (Jan. 1968).

[4] Wagman, D. D., et al., Selected Values of Chemical Thermodynamic Properties, Nat. Bur. Stand. (U.S.), Tech. Note 270-4, 141 pages (May 1969).

[5] Wagman, D. D., et al., Selected Values of Chemical Thermodynamic Properties, Nat. Bur. Stand. (U.S), Tech. Note 270-5, 37 pages (Mar. 1971).

[6] Parker, V. B., Wagman, D. D., and Evans, W. H., Selected Values of Chemical Thermodynamic Properties, Nat. Bur. Stand. (U.S.), Tech. Note 270-6, 106 pages (Nov. 1971).

[7] Rossini, F. D., Pitzer, K. S., Arnett, R. L., Braun, R. M., and Pimentel, G. C., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Am. Pet, Inst. Res. Proj. **44**, Carnegie Press, Pittsburgh, Pa. (1953).

PUBLICATIONS of the National Bureau of Standards*

PERIODICALS

Technical News Bulletin, Annual subscription: Domestic, $6.50: foreign, $8.25. Single copy price, 65 cents. Available on a 1-, 2-, or 3-year subscription basis. SD Catalog No. C13.13.

Journal of Research of the National Bureau of Standards

Section A. Physics and Chemistry. Issued six times a year. Annual subscription: Domestic, $9.50; foreign, $11.75. Single copy price varies. SD Catalog No. C13.22/sec.A.

Section B. Mathematical Sciences. Issued quarterly. Annual subscription: Domestic, $5; foreign, $6.25. Single copy, $1.25. SD Catalog No. C13.22/sec.B.

Section C. Engineering and Instrumentation. Issued quarterly. Annual subscription: Domestic, $5; foreign, $6.25. Single copy, $1.25. SD Catalog No. C13.22/sec.C.

NBS BIBLIOGRAPHIC SUBSCRIPTION SERVICES

Cryogenic Data Center Current Awareness Service (Publications and Reports of Interest in Cryogenics). A literature survey issued weekly. Annual subscription: Domestic, $20.00; foreign, $25.00.

Liquefied Natural Gas. A literature survey issued quarterly. Annual subscription: $20.00.

Superconducting Devices and Materials. A literature survey issued quarterly. Annual subscription: $20.00. Send subscription orders and remittances for the preceding bibliographic services to the U.S. Department of Commerce, National Technical Information Service, Springfield, Va. 22151.

Electromagnetic Metrology Current Awareness Service (Abstracts of Selected Articles on Measurement Techniques and Standards of Electromagnetic Quantities from D-C to Millimeter-Wave Frequencies). Issued monthly. Annual subscription: $100.00 (Special rates for multi-subscriptions). Send subscription order and remittance to the Electromagnetic Metrology Information Center, Electromagnetics Division, National Bureau of Standards, Boulder, Colo. 80302.

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TEMPERATURE *continued*

manometer by means of a diaphragm, the position of which is established by capacitance techniques. The amount of gas in the small metal tube running through the temperature gradient between the diaphragm and the cylinder must of course be known and accounted for in the calculations. A special capacitance-probe technique was developed for determining the diameter of the small bore (approx. 0.9 mm diameter) metal tube, giving an estimated uncertainty of 0.6 μm in lengths of 1 meter.[3] In addition, a series of 13 thermocouples, placed at 2.5 cm intervals, is used to measure the thermal gradient along the tube.

The work is currently being extended to higher temperatures, the ultimate objective being measurements up to the gold point. The gold point is of special importance as it is the fixed point on the IPTS between the Pt-Pt10 percent Rh thermocouple and the optical pyrometer, which has only the one reference temperature. A more accurate value of the temperature of the gold point on the thermodynamic scale would make it possible to attain greater accuracy in thermodynamic values of all measurements made at higher temperatures with radiation instruments.

This project illustrates the talent, effort, and long-term dedication that is required when working at the leading edge of measurement science. Work on this principle of the manometer began decades ago, and Dr. Guildner and Mr. Edsinger have devoted full time to the gas thermometry project since joining NBS in 1959.

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